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THE DEVELOPMENT AND UTILIZATION  
OF TECHNOLOGY IN INDUSTRY

by

William H. Cruber

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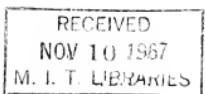
THE DEVELOPMENT AND UTILIZATION  
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ABSTRACT

The willingness and/or ability to invest in the development and/or utilization of new technology is found to be a function of three factors:

- (1) Size of market (need);
- (2) Size of firm; and
- (3) Competitive pressure.

The process of interaction between these three factors is examined, and some industry examples are provided.



THE DEVELOPMENT AND UTILIZATION OF TECHNOLOGY IN INDUSTRY\*\*

[Paper prepared for Gruber, W.H. and D.G. Marquis (Editors).  
The Human Factor in the Transfer of Technology (forthcoming)].

This paper might have as a subtitle, "The Economic Factor in the Transfer of Technology" because industrial activity in the United States is primarily an economic activity. Companies decide to invest in research and development (R&D); they allocate marketing resources in attempts to achieve the transfer of technology that is embodied in their products; and they purchase new equipment which frequently involves the acceptance of new technology. All these decisions are based upon the economic return expected as a result of innovations that they have adopted.

The focus of this paper will be the critical economic forces that appear to determine the willingness and ability of companies to invest in (1) the development of new technology; (2) the utilization through marketing efforts of the new technology that they develop; and (3) the new technology available for utilization in their own operations that has been developed in other companies.

Three determinants of the willingness and ability of companies to undertake these forms of technological development and utilization will be analysed: (1) competitive pressure, (2) size of market (need) and profitability, and (3) size of firm. These are not mutually exclusive forces,

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\*\* A review of the papers presented at the Conference indicated that the relationship between the human factor and economic forces had not been covered. This paper was written after the Conference to be included in order to cover this facet of the question. The comments on an earlier draft of this paper from Otto Poensgen and Donald Marquis and the research assistance of Herbert Cremer are acknowledged with appreciation. Research funds from the MIT Center for Space Research (funded by NASA Grant NsG 496 are acknowledged with appreciation.



and their interrelationship will be part of the analysis that follows. As their effect on the development and utilization of technology in industry is sometimes negative, both positive and negative examples will be given in the discussion of their impact; and a balanced presentation of their effect will be attempted. Because of the interrelationship between the factors and because the factors have varied (both positive and negative) consequences in different industries, a summary section will provide an integration of the three factors in the overall process of development and utilization of technology in industry.

In order to make manifest the relationship between the human factor and economic forces in the development and utilization of technology, the steel industry will be used as an example in the analysis of each of the three economic determinants of the willingness and ability of companies to develop, utilize, or achieve the utilization of new technology.

#### 1. Competitive Pressure

A company may invest in R&D in order to develop new technology or may quickly accept new technology that becomes available -- not because it wants to, but because it has to. An example of the steel industry in the United States during the postwar period will demonstrate that investment in the development of new technology and in the acceptance of new technology that has been developed elsewhere, may result in the paradox of an industry which is developing and utilizing new technology more and enjoying it less.

It is important to emphasize that there are both the willingness and the ability aspects of the question. During the earlier part of the nineteenth century, the American iron and steel industry received most of its technological knowledge and techniques from Europe and frequently



there were difficulties in application, due to the low level of metallurgical competence in the United States (Strassman, 1959, p. 23). Chemists were at work in the iron industry in Germany in the 1830's but it was not until 1870 that the first chemist (trained in Germany) was employed by Carnegie (Strassman, 1959, p. 52). In the United States, "the unsuccessful attempts to smelt with coke or anthracite; to make crucible, Bessemer or open-hearth steel before 1870; or to apply the Siemens Direct, Ellershausen or Clapp-Griffiths processes after 1870 -- all involved chemical properties and processes that were not fully understood" (Strassman, 1959, p. 52).

The willingness to borrow Europe's technology and the availability of European trained immigrants permitted the gradual development of the U.S. iron and steel industry and some time around the 1870's there occurred a take-off during which the rate of development of the steel industry increased so rapidly that by the early 1900's:

"The output of American furnaces was almost twice as great per furnace as that of English and French furnaces. At the best American furnaces, workers were more than three times as productive as workers at the best German furnaces,

partly through the use of better ores and more fuel.

By 1900 British and German ironmasters were studying and imitating American furnace construction and practice."

(Strassman, 1959, p. 41)

This change in the relative productivity of the U.S. industry in a few decades was a result of the three factors that were cited as the determinants of the willingness and ability to develop and utilize new technology: (1) competitive pressure, (2) size of market and profitability, and (3) size of firm. There is also no question, of course, that the increase in the use of chemists, and the general improvement in the level of technical skill



were factors of importance. The ability to import chemists from Germany, however, and the general increase in technical skill may have been partially a result of the three economic factors.\*

The period during and after the Civil War was one of rapid growth in the U.S. economy that expanded the market for iron and steel. From 1880 to 1900 pig iron production increased from 4.2 to 15.4 million tons and total steel production increased from 1.4 to 11.4 million tons (Fisher, p. 128). Temin (1966, Chapter 10) has a section on the volume of production in which he notes the introduction of the protective Morrill tariff in 1861 and other tariff protection until 1900 as an important factor in this increase in volume.

It may seem to be in conflict with this assertion that a protective tariff limiting foreign competition should be called a favorable action when one of our three major factors explaining the development and utilization of technology is competition. In this case, when competition from foreign producers was reduced by the tariff, Andrew Carnegie was refusing to cooperate with the steel pools in the United States. This prevented the decrease in foreign competition from resulting in a lack of competition. Strassman (pp. 45 and 46) quotes Hendrick (1932) who provides evidence that Carnegie was (a) not willing to share when he had a competitive advantage and (b) understood and practiced marginal cost pricing:

- (a) Hewitt, I am tired of this beam pool and I'm going to get out of it. . . I can make steel cheaper than any of you and undersell you. The market is mine whenever I want to take it. I see no reason why I should present you with all my profits. (p. 45)

\* Strassman (p. 53) notes that as late as 1871 "ignorance of chemistry led to the failure of William Bulcher's open-hearth furnace. . ." The weakness of metallurgical knowledge was alleviated, in part, by the action of the United States Government when it established in 1875 the United States Commission on the Tests of Iron, Steel, and Other Metals.



(b) If we get a small profit per ton, well, if we cannot get a profit per ton, well also, though not so well. If we have to take orders at a slight loss, as we have in the past, I would take them. For many months I saw red marks across certain sales which denoted they were taken at a loss, but I always said to myself, "this loss is gain." (p. 46)

As a result of such behavior and his development or acceptance of a number of major innovations,\* Carnegie was able to expand his operations and achieved scale economies to the level where, by the early 1870's, the Carnegie works in Pittsburgh had "the largest Bessemer plant, the largest crucible plant, the largest steel-rail mill, and the largest steel-freight car works in the world (Oliver, 1965, p. 322). Early U.S. steel industry performance may be summarized by Carnegie's dictum that the nation that made the cheapest steel would "have all other nations at its feet! That was his creed: produce steel cheaper than anyone else in the world" (Oliver, 1956, p. 321).

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\* An attitude that creates competitive pressure has importance only if it is held by a powerful force in an industry. Carnegie's attitudes were backed by his: (1) skill in the selection of key personnel (such as Charles Schwab, Henry Frick, John Lushman, and Captain "Bill" Jones; (2) his willingness to expand his operations during depression; (3) the level of profitability generated by good management; and (4) the introduction of major innovations such as the first large American blast furnace, a machine for cooling slag, improved furnace linings, automatic loading machines, first to apply Thomas-Gilchrist process to regular commercial production in the United States, the Jones mixer, use of high pressure steam to keep ingots under pressure while cooling (Strassman, p. 44). This rare combination of key personnel, an aggressive attitude for expansion, sound business judgment and the resulting introduction in his operations of critical innovations, plus the economies of scale that are associated with both size of firm and the integration of operations -- gave Carnegie an impact on the development of the American iron and steel industry that deserves attention in an analysis of the factors leading to the development and utilization of technology in the growth of the American iron and steel industry. He had a major impact on all three of the factors that we are analyzing as the determinants of the development and utilization of technology.



It is interesting to recall Stephen Toulmin's lament in his paper that the English had done a fine job of developing technology during the postwar period of World War II but had been very poor at the utilization of the new technology that they developed (citing as an example the fact that the hover craft, developed in Britain, was put into first commercial utilization by a Swedish firm). During the latter part of the nineteenth century when the U. S. firms were to surpass their British competitors, it was often U. S. firms that put into full commercial utilization the technology developed in Britain. Fisher (1956, p. 130) notes, for example that the Thomas-Gilchrist basic process for eliminating phosphorous was invented in Britain<sup>\*</sup> but was put into commercial use elsewhere while its use was not applied in Britain for some time after its development there. The decline of the British iron and steel industry and its rise in the United States and Germany are shown in Table 1.

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\* It was Andrew Carnegie who bought the rights in the United States (Strassman, 1959, p. 44). Fisher's reference indicated that the German and Belgian firms were faster in picking up this process than the British.



Table 1. Per Cent of Major World Markets in Iron and Steel Maintained by Various Countries, 1878-1913

	Per Cent of Sales in World Trade of Steel Exports		
	Britain	Germany	United States
1878	69	22	--
1895	57	31	2
1910	38	36	12
1913	39	30	18

Source: Fisher, 1956, p. 13.

In marked contrast to this earlier performance of the U.S. steel industry, the post-World War II period has witnessed the U.S. steel industry on the wane. An inability to control labor costs (Blough, 1963) and complaints of "dumping" when foreign competition cut into its domestic markets (Mooney, 1963) are symptoms of this decline in the fortunes of the U.S. steel industry during the postwar period. It is unlikely that Andrew Carnegie would ever have made the statement made by Roger Blough that we are raising prices to be better able to compete against foreign producers (Blough, 1963).

The lag by U.S. steel firms in the introduction of the basic oxygen furnace (BOF)\* is perhaps the most serious example of shortsightedness. From 1947 when Belgian Patent No. 468,316 was opened for public inspection, there was little reason why the U.S. steel industry did not respond to this innovation. The first commercial plant went into operation in the

\* Described by A. C. Adams, President of Jones and Laughlin in 1959 as "the only major technological breakthrough at the ingot level in the steel industry since before the turn of the century" (Adams and Dirlam, 1966, p. 169). For a more complete account of the lag in the introduction of the basic oxygen process see Adams and Dirlam (1964, 1966).



VOEST Austrian works in 1952. It was reported in 1951 that capital investment of BOF would be only about 60 per cent, labor costs only 50 per cent, and operating costs only 72 per cent of an open-hearth operation (Adams and Dirlam, 1966, p. 177). Despite a history of evidence of the value of the BOF which even included reports by the first U. S. innovator in 1954, McLouth Steel, the two largest U.S. steel producers, U.S. Steel and Bethlehem, did not have BOF in process until 1964.

The loss of world markets and the rise of the percent of U. S. consumption from imports are made manifest in Figure 1. The lag in the introduction relative to the rest of the world in the BOF is given in Table 2.

Table 2. The Lag in Adoption of the Basic Oxygen Process

Year	Annual Oxygen Process Steelmaking Capacity (millions of tons)	
	U. S.	World
1953	--	0.5
1954	--	0.9
1955	0.54	1.9
1956	0.54	2.0
1957	0.54	2.7
1958	1.35	5.2
1959	3.58	9.5
1960	4.16	11.5
1961	4.65	17.2
1962	7.50	24.7

Source: Adams and Dirlam, 1966, p. 182.

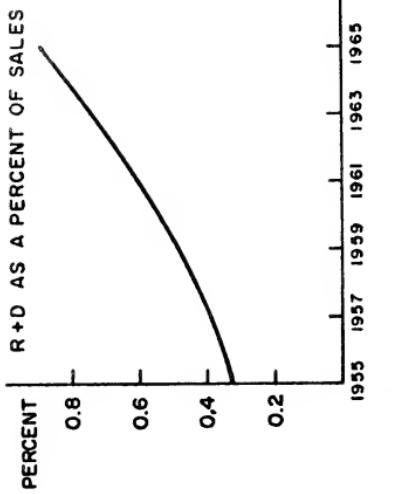
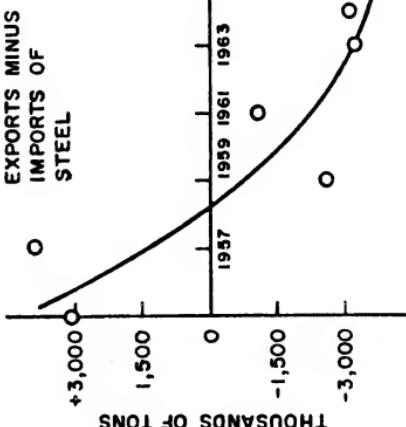
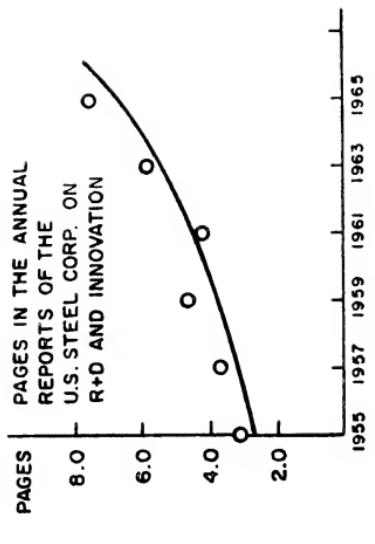
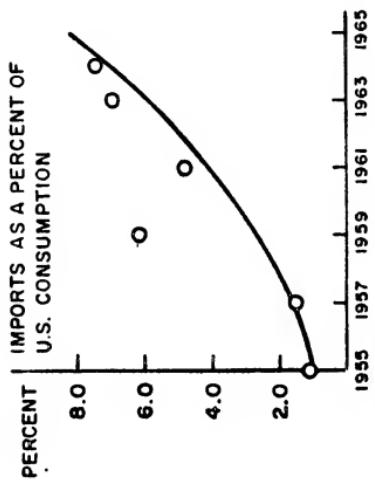
The technical lag and the loss of world markets are understated in Figure 1 and Table 2. The basic oxygen process was initially more



## THE UNITED STATES STEEL INDUSTRY:

## CHALLENGE AND

## RESPONSE



SOURCE : SEE STATISTICAL APPENDIX FOR SOURCES AND METHODOLOGY



suited for the low phosphorous ores of the U. S. than for the high phosphorus ores of Europe. A significant proportion of the U. S. exports of steel results from required purchases under U. S. foreign aid programs (Council of Economic Advisors 1965, pp. 19-20) and would be lost without this aid. Table 3 indicates that the U. S. steel industry also did not fare well in competition with other materials.

Figure 1 indicates, however, that the managers of the U. S. steel industry reacted to the loss of their markets with an increase in their awareness of the value of innovation. It is clear that the managers of the steel industry are more willing to accept innovations; are more willing to experiment with new technology; and have improved the technical capabilities of their operations. Here is an interesting case where the economic factor has resulted in a change in the human factor. A section of a speech by Roger Blough, Chairman of the Board of U. S. Steel (1965) is indicative. After noting that his company's advertising theme is "United States Steel: Where the Big Idea is Innovation," he stated:

Our research expenditures today are three times as great as they were only ten years ago, and I wish they could be even greater. Over twelve hundred research projects were under way in our laboratories last year; and out of these, new or improved products have been coming at an average rate of one a week. Such is the pace of change in steel today. . . .\*

Then, only a few days ago, I saw two steel girders that had been fastened securely together with a couple of steel nails. . . . That's right, two steel nails only slightly thicker than ordinary shingle nails, and after they had been driven through nearly half an inch of steel, their points were still as sharp as though they had merely been hammered through a shingle! Spectacular? No, perhaps not; but, to me, fascinating at least.

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\* It was observed earlier that businessmen may find themselves innovating and transferring more and enjoying it less because of the economic factor. When competitors are invited in because of a vulnerability position, it is very difficult to send them away. In the decade 1955 to 1965 during which U.S. Steel tripled its research inputs, its sales increased by only 10 percent and its profit margin on sales fell from 9.0 percent in 1955 to 6.2 percent in 1965. (U.S. Steel Annual Report 1965, p. 29).



Table 3: The U. S. Material Producing Industries:  
Output Changes during the Postwar Period  
(1947 to 1964)

	Annual Percentage Change in Industrial Production
Iron and Steel	1.7
Glass and Pottery Products	3.3
Cement	3.6
Aluminum	9.4
Plastic Materials	16.9

Source: Council of Economic Advisors, 1965, p. 24.

And so we have among our new products today steel foil that is paper-thin, yet so strong you can bounce a bowling ball off it...pencil-thin wire that will support the weight of a freight car, and transmission line pipe with thinner, stronger walls to cut the cost of transporting gas and oil. So new that they are not yet on the market, we also have sheets of steel that are vapor-coated with aluminum and other metals. And there are many, many more new products, new types of equipment, and new processes to come; for the forces and pressures of competition have never been greater than those we face today from within and without our industry (emphasis added) (pp. 6-7).

Although it was the economic factor that precipitated the changes, the response of the people is the sort of phenomenon that is grist for David McClelland's mill. Steel executives view the ten billion dollar investment expected to be spent in the five years from 1963 to 1967 as something very new to the industry. ARMCO's new president, C. William Verity, Jr., observed: "Never has our industry experienced so much change as it is experiencing now. There is an awakening in every phase of the business -- in management, marketing, research, and reconstruction" (McDonald, 1966, p. 130). In an evaluation of this transformation, McDonald observed:

"The current billions are going into new technologies that are transforming U. S. steelmaking for oxygen furnaces, more sophisticated hot-strip mills, continuous casting, computer-controlled production and new processes that improve the quality, strength, and versatility of steel.



All along the line from mine to mill, old equipment and old ways of making the most basic commodity of industrial society are giving way to the new.

The industry launched this all-out drive under do-or-die pressure to raise its productivity and lower its costs, to upgrade its product lines, and tailor them more closely to customers' needs and specifications -- in short, to enhance its competitiveness. The goal is simply to regain and hold markets lost to aluminum, reinforced concrete, plastics and other materials, to beat back the sharply increased competition from abroad, and in the process, of course, to lift profits out of the slough into which they had fallen almost a decade ago (p. 132).

The rise, fall and recovery of the U. S. steel industry that has been analyzed does not inform us why this pattern occurred. David McClelland, when presented with this evidence, asked why the U. S. steel industry fought back under competitive pressure. He observed that a number of manufacturers in India were closing down under pressure from foreign competition and the introduction of synthetic materials.

No. R. A second question that should be raised is the cause of the decline. The answers to these two questions, however, need not be given here, as the purpose of the example was to present evidence of the force of competitive pressure in the process of transfer.



## 2. Size of Market (Need) and Profitability

Thomas Carlyle called economics a dismal profession. One might concur with his finding from the evidence presented in the competitive pressure section. The economic factor is not all about negative forces -- men acting from fear or reacting after losses.

Another and more positive form of human motivation is a response to observed opportunity. A question was raised several times at the conference whether progress in science and technology came first and then had to be sold -- that is, whether markets had to be developed after new technology became available. The alternative to this first sequence (which might be labelled the "technical perspective") is a view that has been put forward most extensively by an economist, Jacob Schmookler (1962, 1966).

The economic model that posits demand will create its own supply of needed technology is somewhat more complex than has been presented in the economic literature. There is enough truth in this concept to warrant a summary of the reasoning and findings that have supported this view of the process of technical change.

The idea that observed need is the dominant force behind invention and innovation has much historical support. The rapid spurt of technical progress that results from wars; the increase in labor productivity and economic development that followed the Black Plague due to a shortage of labor are historical examples that come to mind. It has been found that the United States has dominated world exports in machinery and other industries that permit high levels of labor productivity (Strassman, 1959, Vernon, 1966, and Gruber, Mehta and Vernon, 1967). The theory that explains this U. S. advantage is based upon the idea of profitability and size of



market as explanatory variables for inventive activity. Historically, the United States has been a labor-short country where wages were relatively higher than in other developed countries. This encouraged inventive activity to increase labor productivity.\* The shortage of labor and the cost of labor made it more profitable to accept new technology. The profitability of using new technology therefore created the larger market for the new technology and thus there was the incentive to invent and the incentive to accept quickly what was invented.

Schmookler (1962, 1966) found that an increase in the rate of patents awarded followed an increase in the output of the industries for which the patented inventions were developed. He also found that the inventions were in response to recognized needs (demand pull) in contrast to scientific or technical progress that then permitted (inspired) new technology to be developed. In his study of about one thousand major inventions in the farming, railroad, petroleum, and paper industries, Schmookler (1966, pp. 66-67) found no science-based stimulation. He did find that a significant number came from economic objectives.

The willingness to develop new technology and the willingness to accept new technology often appear to be related. This is particularly true in cases where the companies engaged in the work of development of new technology are paid for this activity by the ultimate user of the advanced technology that is developed. Mission oriented R&D in the defense industry

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\* For example, Habakkuk (1966) analyzed the response to scarcity and high costs of some factors in a comparison of technological innovation in the United States and England in the nineteenth century. "Where labor is scarce, innovation occurs to increase labor productivity; where land is free and labor is scarce, the machines (farm equipment) are invented because it is better to cultivate more (acreage) than well (yield per acre)." (pp. 100-101).



is an example of this phenomenon. A need perceived first by a potential customer who then requests that the new technology be developed by a supplier is probably the case where the transfer of new technology occurs with the greatest speed (Sherwin and Isenson, 1967).

The calculus of economic costs also helps to explain the relationship between the willingness to develop new technology (due to demand pull) and the willingness to accept new technology.

Average unit costs are calculated: \*

$$AC = \frac{TC}{Q} = \frac{FC + VC}{Q}$$

Where: AC = Average cost per unit

TC = Total costs

Q = Quantity produced

FC = Fixed costs

VC = Variable costs

A large component of fixed costs for many manufacturing operations is depreciation on equipment. In capital equipment decisions (which affect the willingness to accept new technology), if there is excess capacity for a given set of equipment, then the relevant costs to consider when making a decision are variable costs -- not full average costs. The fixed costs component of average costs is by definition "fixed," and does not enter into the decision process.

In the steel industry in the United States, with a low rate of increase during the latter part of the postwar period in the demand for steel,

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\* For a more extended analysis of the nature of costs in economic decisions, see Samuelson (1967, chapter 24); or Anthony (1964, chapters 16 and 18).



decisions for new equipment such as the BOF had to be made for replacement; not for an expansion of capacity. In such a situation the full average costs of producing steel with a new BOF had to be lower than the variable costs from the use of existing open hearth furnaces. The nature of costs helps to explain why the United States Steel Corporation, with the last major open hearth operations installed in the United States (the Fairless Works), was also the last of the large steel corporations in the United States to install BOF. The nature of costs does not explain why the United States Steel Corporation was the last major corporation to invest in obso-lete equipment.

The rate of growth in demand therefore helps to explain both the relative willingness to develop and/or to accept new technology as it becomes available. This effect applies to the level of total economic activity (GNP) and it is for this reason that Myers (1967, p. 143) was correct in extrapolating from his research:

Perhaps the best way to stimulate innovation is to stimulate the economy as a whole. . . . about one-half of the innovations\* came about in direct response to market factors. A rapidly growing economy obviously expands the market for innovations and encourages business investment in new ideas.

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\* Myers was director of the National Planning Association R & D Utili-zation Project. This finding was one of the conclusions reached from an analysis of over 500 innovations in this NPA study.



It was observed in the previous section on competitive pressure that the steel industry in the United States was expanding rapidly in capacity during the latter part of the nineteenth century, and it was also observed that the British steel industry was failing in performance relative to the steel companies in other major industrial countries. We do not know the reason that technology developed in Britain was used first in other countries. It is relevant to observe that the rate of growth in industrial production in Great Britain during the period 1870 to 1910 was half the rate of increase that was experienced from 1800 to 1870\*

The importance of profitability in the speed of transfer has been rigorously studied by Edwin Mansfield. In a study of the iron and steel,

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\* Calculated from data in Mitchell (1962, pp. 271-272). Historical statistics are only approximations due to the quality of data collection. A difference of a factor greater than two can, however, be used with some confidence that a difference of some magnitude did exist.



bituminous coal, railroads and brewery industries, Mansfield (1961, 1963a) found that the probability of a firm's introducing a new technique was an increasing function of profitability and the proportion of firms doing it and a decreasing function of the size of investment required.\* In a further study of the speed of diffusion of a new technique within a firm, Mansfield (1963b) found again that it was a function of the level of profitability. Note, however, that the speed of acceptance of new technology is a somewhat different question than the nature of technical activity which determines the availability of new technology to be transferred. Both facets of technical progress should be examined in a study of the process of transfer because the process that determines utilization also affects the development of technology to be transferred with utilization.

There is another school of thought on the source of inventive activity. This school finds that technical activity is a breeding process that produces the new out of a stock that has been developed over time. Inventors are not motivated by recognized social need or the opportunity for profit (Rossman, 1931), but invent because of the need to create or other personal motives. The Schmookler (1962, 1966) Gilfillan (1935) thinking that finds need dominates what is invented has been questioned by Cohen (1931) who observed:

That human volition by itself is, apart from favorable circumstances and mechanisms, inadequate to produce social results, is ancient wisdom. Yet after an event has happened we are prone to look upon volition as the producing cause. A striking illustration of this fact is the way we explain inventions as due to the need of them. We are inclined to forget the great multitude of human needs that have gone unsatisfied through the ages (p. 342).

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\* With reference again to the rise of the iron and steel industry in the latter part of the nineteenth century, Temin (1964, pp. 212-213) notes the profit effect of the protective tariff enjoyed by the industry. This same protective tariff reduced the volume of exports shipped into the United States by British steel companies. One would expect that expanding industries would be more profitable than ones that were declining or relatively stagnant in terms of growth, and profitability



In fact, as the papers in this volume indicate, the determinants of inventive activity and the speed of acceptance of new technology are more complicated than the "need" school recognizes. Human factors and the process of science and technology must also be considered.

Nelson (1959) went part way in bringing together the schools of thought on this issue. He observed that technical activity is subject to Marshall's two-blades-of-a-scissors rule. Need creates opportunity; the level of technical knowledge may lower the cost, and this combination of need and cost (two blades of scissors) will determine, to some degree, the technical activity that takes place. Nelson has given a multi-factor answer that is not as inclusive as the findings in this volume, although it does move in the direction of the findings presented here.

### 3. Size of Firm

It is obvious that size of firm affects and is often a result of competitive pressure and size of market, the first two critical factors that have been analyzed. If it is assumed that the ability to utilize or affect the utilization of technology is closely related to the willingness and ability to invest in the R&D necessary to develop new technology, then it is clear that large firms in all countries are the ones that develop most of the new technology that ends in utilization.

The "technology gap" and the "technological balance of payments" are new expressions developed within the last few years to describe the problems of the firms in Europe, where even the largest firms are much smaller than their U.S. competitors. For example, in 1965 the United States Steel Corporation had sales almost four times those of the largest non-U.S. steel corporation, August Thyssen Hütte (Fortune, 1966).



Now there is no question but that the majority of R&D is performed in the largest firms in an industry. In the United States in 1964 the largest eight firms in almost every industry performed well over half of the R&D in that industry (NSF, 1966, p. 33). L. Soutendijk (1967, p. 138) has noted that in Holland 52 percent of all R&D for the total country is done by only five firms. Soutendijk accepts the common European view that size of firm is the reason for the technology gap. This view seems so well accepted in Europe that the perceived advantage of the large American firm has become a critical source of anti-American public opinion (Lewis, 1967).

The French, German, Dutch, English, and Japanese governments have been actively attempting to merge firms in order to compete better with the large U.S. firms.\* At the same time, United States antitrust policy is predicated on the idea that small firms are good and efforts are made to block mergers in the United States (Markham, 1962).

Some comment seems necessary to explain the apparent conflict between the efforts in other countries to foster mergers in order to achieve scale economies comparable to the advantages seen to exist for U.S. firms and the efforts in the U.S. to restrict merger activity and limit the size of firms because both sets of actions are policies that are designed to achieve the utilization of new technology.

The Panel of Invention and Innovation (1967) found that a significant proportion of the major twentieth century inventions came from independent inventors or small firms. The Panel reviewed the literature on size and invention and innovation as follows:

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\* The magnitude of this effort deserves attention. In France during the first eight months of 1966 there were more than 1,600 intercompany agreements to associate or combine in one way or another. (Fortune, February, 1967, p. 74.)



Professor John Jewkes, et al. (1958) showed that out of 61 important inventions and innovations of the twentieth century, which the authors selected for analysis, over half of them stemmed from independent inventors or small firms.

Professor Daniel Hamberg (1963, p. 96) of the University of Maryland studied major inventions made during the decade 1946-55 and found that over two-thirds of them resulted from the work of independent inventors and small companies.

Professor Merton Peck (1962) of Harvard studied 149 inventions in aluminum welding, fabricating techniques and aluminum finishing. Major producers accounted for only one of seven important inventions.

Professor Hamberg (1963, p. 98) also studied 13 major innovations in the American steel industry -- four came from inventions in European companies, seven from independent inventors, and none from inventions by the American steel companies.

Professor John Enos (1962) of the Massachusetts Institute of Technology studied what were considered seven major inventions in the refining and cracking of petroleum -- seven were made by independent inventors. The contributions of large companies were largely in the area of improvement inventions.

Other findings (e.g., Comanor, 1965; Mueller, 1962) also indicated although there has been that large size was not necessary for innovation and/ despite some quantitative evidence by Mansfield, 1963b) that larger firms utilized innovations faster than smaller firms, \* economists in the United States have been impressed far more than has been the case of Europeans with the need to protect small firms and private inventors.

Despite some contrary opinions in defense of the need for large firms (e.g., Schumpeter, 1947), economists in the United States and official United States public policy has been in favor of protecting the smaller firms. Donald Turner, Chief of the Antitrust Division of the Department of Justice, has expressed concern that a new company

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\* The steel industry was an exception in Mansfield's set of findings by industry.



with inadequate resources for marketing may be "locked out of the business, no matter how good its product may be" (Turner, 1966, p. 44).

The question of size of firm and the level of competition must often be linked together. Industries with many small firms are thought to be more competitive than industries where large firms predominate. Jewkes, et al (1958), although strongly influenced by the advantages to small size, give in Chapter VII a somewhat balanced picture of the advantages as well as the disadvantages of large size. And it is true that, based upon one's selection of industry, it is possible to reach firm conclusions about the need for/against large/small size in order to provide/prevent the competition/protection needed for the development and utilization of technology in industry.

Pugh-Roberts Associates (1966) in an "Advanced Systems Analysis of Textile Industry Problems" developed a feedback model (p. 45):

- (1) Low profit rate and lack of growth
- (2) Low investment rate
- (3) Little new equipment, processes and products
- (4) Back to (1) low profit rate. . .\*

Economists have not solved the problem of the effect of a firm's size and level of competition on the introduction and utilization of technology. On balance, when the disadvantages of large size are factored in, there appears to be a trend toward advantages to scale, and we may be watching a lag in the thinking of economists in the United States.

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\* For a more general analysis of this problem, see "Problems of Innovation in American Industry," and "Patterns and Problems of Technical Innovation in American Industry" (Washington, D.C.: U.S. Department of Commerce, Office of Technical Services, 1963).

For a general review of the larger question of competition and scale, see Edwin Mansfield, ed., Monopoly Power and Economic Performance (New York: Norton, 1964).



Gruber, Mehta and Vernon (1967) found that size was related to firms with the greatest trade advantage in manufactured products. The development and utilization of new products and processes appears to be increasing in complexity. A complete analysis of total industrial activity over time would be a valuable contribution (the Gruber, Mehta and Vernon findings were based upon international trade performance in 1962).

The fact that the development of new technology is often a different activity than the process of gaining acceptance (utilization of new technology is often neglected when economists sit down to argue on this problem. The important link between the development and achievement of utilization of new technology is often neglected as one reads the professional literature.

As the conclusion to this section on size of firm and the development and utilization of new technology by industry, it may be useful to cite from the Business Week (1966, pp. 113-114) review of the world computer market:

#### A Game for Giants

Huge chunks of capital are going into the competition for shares of this fast-increasing market. To contend in this business requires massive investment, for the computer has a unique position as a product in the world market. The millions of dollars that have to be spent to make the hardware represent only a part of the story. At least as much again must be invested in programming the machines, building up service facilities, and training and maintaining the staffs to support the customer in his use of the machine.

Says Otto Stitz, Univac's manager in West Germany: 'Anyone can make a computer. The trick is in putting it in the user's hands, equipped and ready to solve his problems.'

The quality of the 'software' and the service determines whether the computer itself will sell in sufficient quantities to be profitable. 'You can't take a "commando approach" on service,' says IBM's Maisonrouge. 'When you sell a computer, it can't be just a hit-and-run deal.'



Top contestants. All this makes it a game to be played mostly by giants. The list of contestants makes that plain enough . . . Of the 18 or so computer makers that have multi-national operations, half are companies with sales (or other equipment as well as computers) exceeding \$1-billion a year.

That gives them strength enough to stay in the race, for only a handful have yet made a profit from their computer business. . . \*

### Conclusion

A large proportion of the transfer of technology takes place as a result of activities in the industrial sector of the economy. In the United States, that means economic factors will have a major effect on the process of development and transfer of technology. It is because of these economic factors that the willingness to invest in the development of new technology is often related to the willingness to adopt new technology. Innovation does not occur, there is no meaningful transfer until there is utilization and the importance of whatever transfer that does take place is usually measured in economic magnitudes (dollars of sales; amount of money saved in cost reduction, etc.).

In order to understand the transfer of technology, economic factors must be considered. Other reviewers of this question (e.g., Horowitz, 1963; Mansfield, 1964) have taken a cautious view of what is known about this question. Due to the low level of understanding, this study concen-

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\* This describes scale advantages in one industry. An industry-by industry study would have to be made to examine the question for all manufacturing activities. That times have changed, however, can be seen from the pressures to integrate economies. The decision by the major aircraft manufacturers in three countries (Hawker Siddeley of Britain, Sud Aviation of France, and Germany's Arbeitsgemeinschaft Airbus) to join together on the jet airbus is an example of the way scale factors have become more important in the development and utilization of technology.



trated on the identification of the economic forces that appeared to be of critical importance. The process through which these forces affect the development and utilization of transfer in industry was analyzed. The interrelationships between the three economic forces that were considered -competitive pressure, size of market, and size of firm--were made manifest and linked with the human factor in the development and utilization of technology.

The rise, fall, and attempts to recover of the steel industry in the United States was given as an example of these economic forces. The process through which these economic forces altered the human factor in the development and utilization of new technology in the steel industry was made manifest.

This steel industry example provided an illustration of the economic forces -- but it also gave evidence of how little is known about the economic factors in the development and utilization of new technology in industry. Why was there such insensitivity to the availability of new technology in the steel industry during the postwar period? Why is there now such a massive effort to recover world technological and economic supremacy?

What would have happened if the president of United States Steel was committed to increasing the market share of his company after World War II? That the motivations of one man could have a significant effect on the nature of competition in a large industry gives an indication of the problems of research methodology in efforts to understand the economic forces in the development and utilization of technology in industry.



The identification in this study of the economic forces is a first step toward further research. We can understand why it is difficult for a small firm to achieve the utilization of new technology in some industries such as computers or large jet aircraft. Why some industries such as textile manufacturing have been slow to develop or utilize new technology can also be partially understood from the economic forces experienced by that industry.

Economic forces provide an incomplete set of independent variables in a study of the development and utilization of new technology in industry. Much of the research even within this partial perspective remains for future efforts by social and management scientists.



REFERENCES

Adams, W. and J. Dirlam, "Steel Imports and Vertical Oligopoly Power," American Economic Review, Vol. 54 (5), Sept. 1964, pp. 625-655.

Adams, W. and J. Dirlam, "Big Steel, Invention and Innovation," The Quarterly Journal of Economics, Vol. LXXX (2), May, 1966, pp. 167-189.

\*--> Blough, Roger M., "My Side of the Steel Price Story," Look, January 27, 1963, pp. 19-23.

Blough, Roger M., "Return of the Native," Address given before the Johnstown (Pa.) Interclub Council, October 13, 1965.

"The \$5-Billion World Market for Computers," Business Week, February 19, 1966, pp. 110 ff.

Cohen, M., Reason and Nature. Glencoe: The Free Press, 1953 - reprint (2nd Edition)

Comanor, W.S., "Research and Technical Change in the Pharmaceutical Industry," Review of Economics and Statistics, May 1965, pp. 182-187.

Council of Economic Advisors, Report to the President on Steel Prices (Washington: The White House, 1965).

Enos, J.L., "Invention and Innovation in the Petroleum Refining Industry," Rate and Direction of Inventive Activity (Princeton: Princeton University Press, 1962, pp. 299-332.

Fisher, D.A., The Epic of Steel. New York: Harper & Row, 1963.

Fortune, "500 Largest United States Corporations," July, 1966: "200 Largest Foreign Corporations," August, 1966.

"Merging to Survive," Fortune, February, 1967, p. 74.

Gilfillan, S.C., The Sociology of Invention. Chicago: Follett Publishing Company, 1935.

Gruber, W.H., D. Mehta and R. Vernon, "The R&D Factor in International Trade and International Investment of United States Manufacturing Industries," Journal of Political Economy, Feb., 1967, pp. 20-37.

Habakkuk, H.J., American and British Technology in the Nineteenth Century. Cambridge: Cambridge University Press, 1966.

Hamberg, D., "Invention in the Industrial Research Laboratory," Journal of Political Economy, Vol. 71, April 1963.

\* Anthony, R., Management Accounting. 3rd ed. Homewood, Ill.: Irwin, 1964.



Hendrick, B.G., The Life of Andrew Carnegie. Garden City: Doubleday, Doran, 1932.

Horowitz, Ira, "Evaluation of the Results of R&D: Where We Stand," IEEE Transactions on Engineering Management, June, 1963, pp. 42-51.

Jewkes, J., D. Sawers, and R. Stillerman, The Sources of Invention. New York: St. Martin's Press, 1959.

Mansfield, E., "Technical Change and the Rate of Imitation," Econometrica, Vol. XXIX (1961).

Mansfield, E., "The Speed of Response of Firms to New Techniques," Quarterly Journal of Economics, Vol. LXXVII (1963a), pp. 290-311.

Mansfield, E., "Intrafirm Rates of Diffusion of an Innovation," Review of Economics and Statistics, Vol. XVV (Nov. 1963b) pp. 348-359.

Mansfield, E., "Size of Firm, Market Structure, and Innovation," Journal of Political Economy, LXXI (1963c), pp. 556-576.

Mansfield, E. (ed.), Monopoly Power and Economic Performance. New York: Norton, 1964.

Mansfield, E., Quoted in "What Is the Key to Progress?" Business Week, May 16, 1964, pp. 132ff.

Markham, J.W., "Inventive Activity: Government Controls and the Legal Environment," in The Rate and Direction of Inventive Activity. Princeton: Princeton University Press, 1962, pp. 587-608.

McDonald, J., "Steel Is Rebuilding for a New Era," Fortune (October, 1966), pp. 130ff.

Mitchell, B.R., Abstract of British Historical Statistics. Cambridge: Cambridge University Press, 1962.

Mooney, Richard E., "Steel Men Lose Suit on Dumping," New York Times, June 20, 1963, pp. 41 and 45.

Mueller, W.F., "The Origins of the Basic Inventions Underlying du Pont's Major Products and Process Innovations, 1920-1950," in The Rate and Direction of Inventive Activity. Princeton, N.J.: Princeton University Press, 1962, pp. 323-346.

★-→ National Science Foundation, Basic Research, Applied Research, and Development in Industry, NSF 66-28. Washington, D.C.: Government Printing Office, 1966.

Nelson, R.R., "The Economics of Invention: A Survey of the Literature," Journal of Business, Vol. XXXII, April 1959, pp. 101-127.

Oliver, J.W., History of American Technology. New York: Roland Press, 1956.

★ Myers, S., "Industrial Innovations and the Utilization of Research Output," in Proceedings of the 20th National Conference on the Administration of Research. Denver, Colo.: Denver Research Institute, 1967,



Panel of Invention and Innovation, "Technological Innovation: Its Environment and Management," Washington, D.C.: Department of Commerce, 1967.

"Patterns and Problems of Technical Innovation in American Industry." Washington, D.C.: U.S. Department of Commerce, Office of Technical Services, September 1963.

Peck, M.J., "Inventions in the Post-War American Aluminum Industry," The Rate and Direction of Inventive Activity. Princeton, N.J.: Princeton University Press, 1962, pp. 279-292,

"Problems of Innovation in American Industry," Washington, D.C.: U.S. Department of Commerce, Office of Technical Services, May 1963.

Pugh-Roberts Associates, "Advanced Systems Analysis of Textile Industry Problems," Report to Textile and Apparel Technology Center, U.S. Department of Commerce, March 1966.

Roszman, M., The Psychology of the Invention. Washington, D.C.: Inventor's Publishing Company, 1931.

Samuelson, P.A., Economics, 7th Ed., New York: McGraw-Hill, 1967.

Schmookler, J., "Economic Sources of Inventive Activity," Journal of Economic History, Vol. XXII, No. 1, March 1962, pp. 1-20.

Schmookler, J., Invention and Economic Growth. Cambridge: Harvard University Press, 1966.

Schumpeter, Joseph A., Capitalism, Socialism, and Democracy (2d Ed.). New York: Harper and Bros., 1947, pp. 81-110.

Sherwin, C.W. and R.S. Isenson, "Project Hindsight: A Defense Department Study of the Utility of Research," Science, Vol. 156, 23 June 67, pp. 1571-1577.

Soutendijk, L.R.W., quoted in Stern, R. (ed.), Technology and World Trade: Proceedings of a Symposium. U.S. Department of Commerce, National Bureau of Standards (Publication 284). Washington, D.C.: Government Printing Office, 1967.

Strassman, W.P., Risk and Technological Innovation: American Manufacturing Methods during the Nineteenth Century. Ithaca, New York: Cornell University Press, 1959.

Termin, Peter, Iron and Steel in Nineteenth Century America. Cambridge, Mass.: MIT Press, 1964.

Turner, D., quoted in "Justice in a Lather over Soap Outlays," Business Week, November 5, 1966, pp. 44-45.



United States Steel Corporation, Annual Report 1965.

Vernon, R., "International Trade and International Investment in the Product Cycle," Quarterly Journal of Economics, May 1966.



STATISTICAL APPENDIX

Figure #: Exports, imports, and imports as a per cent of United States production from Council of Economic Advisors, Report to the President on Steel Prices (Washington: The White House, 1965, p. 13). Recent evidence reported in The Wall Street Journal (June 20, 1967, p. 1) indicates that the trends plotted have continued through 1966 when the percentage was 11 per cent of U.S. consumption. The trend in the level of R&D/sales was calculated in the following manner. An average for the industry was taken from National Science Foundation, Basic Research, Applied Research and Development in Industry, 1964 (Washington, D.C.: NSF 66-28, p. 62). The shape of curve was calculated by the information quoted from Roger Blough that research inputs at U.S. Steel had tripled. Sales of U.S. Steel had barely increased, and therefore we were able to assume that intensity (R&D/sales) had almost tripled. The curve was calculated from the growth rate noted by Roger Blough and then we solved an exponential growth equation of the form  $Y=Ae^{-t}$  based upon the above parameter. It is an estimate of how the curve would appear if R&D/sales at U.S. Steel had changed from a little over .3% in 1955 to .9 per cent of sales in 1965. The actual R&D/sales of U.S. Steel may vary from the estimate on the Y axis in any given year in the figure, but the shape of the curve provides an indication of the steepness of the slope or rate of increase in research intensity at U.S. Steel.

The trend in pages on innovation and R&D in the United States Steel Corporation annual reports is based upon a three-year moving average of every other year. The calculation of the number of pages was done at a meeting with two graduate students in metallurgy, Howard Pielet and Guy Delaval together with the author and a research assistant, Herbert Cremer, in order to arrive at an evaluation of annual report content analysis that was based upon the opinions of several observers. The slope approximate an earlier report that suggested this measure of awareness, Edward Matulevicius, "The Trend to a Growth in Research and Development in the Steel Industry (term paper by an MIT student prepared for a course taught by W.H. Gruber, Spring, 1966, p. 16).

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